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(54) Method of casting powder.

(57) In the method of the invention, the formability is imparted to the slurry of a metal or ceramic powder by employing a porous mold and removing the dispersion medium through the evaporation or thermal decomposition thereof, or by using a silazane oil as the dispersion medium and curing it by heating. Since the phase change usually accompanying volume change does not occur in the dispersion medium, the strain and deformation rarely occur in the molded body. As a result, the sintered body obtained has a highly dimensional accuracy.

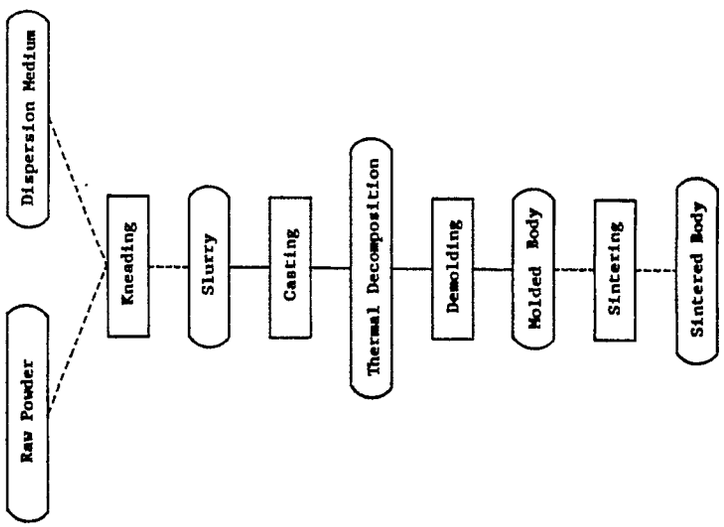

FIG. 1

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METHOD OF CASTING POWDER

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to a method of casting a metal or ceramic powder which comprises suspending the powder into a liquid dispersion medium to form a slurry and casting the slurry into a mold.

Description of the Prior Art

Casting method is known as a molding method of metal powder, ceramic powder, and a mixture of metal powder and ceramic powder.

The inventors disclosed in Japanese Patent KOKAI No. 62-192502 a molding method of metal powder or ceramic powder which comprises suspending the powder into a dispersion medium of which the principal component is a material having a melting point of 0 to 100 °C being extractable with liquid or supercritical carbon dioxide, and casting the slurry into a liquid-unabsorbable mold. In this method, the cast slurry is cooled to freeze it, and then demolded. Subsequently, the principal component of the dispersion medium in the frozen body is extracted with liquid or supercritical carbon dioxide. The extracted body is heated, and the residual dispersion medium is removed by thermal decomposition. The molded body thus obtained is densified by sintering to obtain a sintered body. An outline of the above process is shown in Figure 8. The sintered body is machined if necessary, and used for a cutting tool, a machine part or the like.

The above casting method of metal or ceramic powder is excellent in obtaining a molded body in a short time without the generation of cracks, but has the following problems. In the above method, the volume change of the slurry occurs during freezing. For example, when paraffin wax is used as the dispersion medium, a volumetric shrinkage of about 25 % occurs. The freezing begins at the portion to touch the mold, and strain generates on the inside of the treated body by the freezing of the outside. Therefore, the freezed body is more or less deformed. By the deformation, the molded body is sometimes broken during demolding. The degree of the deformation sharply varies according to the temperature of the slurry, casting pressure, the temperature of the mold cooling dispersion medium and pressing time, and therefore, suitable casting conditions must be set requiring trial and error experiments for a long time. The internal strain occurred in the molding process is released during the extraction with a supercritical fluid or a liquefied gas, thermal decomposition or sintering, and deformation proceeds to decrease accuracy to size. In the case of a big profile body, the above problems are more remarkable.

SUMMARY OF THE INVENTION

An object of the invetion is to provide a method for casting a metal or ceramic powder which is excellent in molding in a short time wherein internal strain and deformation occur little and a sintered body having a highly dimensional accuracy can be obtained.

Another object of the invention is to provide a method for casting a metal or ceramic powder which does not require trial and error experiments for setting the casting conditions.

Still another object of the invention is to provide a method for casting a metal or ceramic powder which facilitates demolding of the molded body.

The present inventors have investigated in order to achieve the above objects, and completed the present invention by employing a porous mold and removing the dispersion medium through the evaporation or thermal decomposition thereof, or by using a silazane oil as the dispersion medium and curing it by heating.

Thus, the present invention provides a method of casting a metal or ceramic powder which comprises casting a slurry of the metal or ceramic powder suspended in a dispersion medium into a prous mold and heating the slurry placed in the porous mold to remove the dispersion medium through the evaporation or the decomposition of the medium. The present invention also provides a method of casting a metal or

ceramic powder suspended in a dispersion medium containing at least 30 wt. % of a silazane oil into a mold, curing the dispersion medium by heating at a temperature of 100 to 200 ° C, and then demolding.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1 and 2 are flow diagram illustrating the method of the invention.
Figure 3 is a sectional view of a mold used for the method of the invention.
Figure 4 is a sectional view of a mold used for a conventional method.
Figure 5 is a sectional view of another mold used for the method of the invention.
Figure 6 is a plan view of a molded body, and Figure 7 is a front view thereof.
Figure 8 is a flow diagram illustrating a conventional method.

DETAILED DESCRIPTION OF THE INVENTION

The powder molded by the method of the invention is a metal powder such as 2 % Ni-98 % Fe mixed powder, SUS 316 powder or high speed steel powder, a ceramic powder such as alumina powder, zirconia powder, silicon nitride powder or silicon carbide powder or a mixed powder of metal and ceramic such as tungsten carbide-cobalt mixed powder or titanium carbide-nickel mixed powder. A suitable particle size of the powder is about 0.2 to 100 μm.

When the dispersion medium is removed by evaporation or thermal decomposition the dispersion medium for suspending the metal or ceramic powder impart fluidity thereto, but the role as a binder for molding is not necessary, different from the conventional method. In the method of the invention, the fluidity of the cast slurry is lost by heating to remove the dispersion medium, and the formability is generated to obtain a molded body. There are many liquids being in conformity with the above object, such as alcohols including methanol, ethanol, propanol and butanol, ketones including acetone, hydrocarbons indluding hexane and benzene, and liquid paraffin. Preferred liquids can be made in a high vacuum state in view of removing by the section of the air which is introduced into the slurry of the metal or ceramic powder by stirring during preparing it. In this regard, liquid paraffin is preferable. The dispersion medium may be composed of such a liquid alone.

While, in the case of curing the dispersion medium by heating, the dispersion medium contains a silazane oil. The silazane oil is a reaction product of a material represented by R_xSiCl_{4-x} ($x = 1.2$, $R = H$, CH_3, C_2H_5, C_6H_5), such as H_2SiCl_2, H_3SiCl, $(CH_3)_2SiCl_2$ or CH_3SiHCl_2, with NH_3, and has a structure of $[H_2SiNH]_m = [(H_2Si)_{1.5}N]_n$, $[CH_3(CH_3NH)Si(CH_3N)]_p$ $[CH_3Si(CH_3N)_{1.5}]_q$, $(CH_3SiHNH)_\gamma(CH_3SiHNCH_3)_s$-$(CH_3SiN)_t$ or the like. It can be obtained in liquid state at ordinary temperature by selecting the reaction conditions. The content of the silazane oil is not less than 30 wt. % for curing the dispersion medium. Otherwise, it does not cure at all, or becomes only gel, and the formability is insufficient. The dispersion medium may be composed of silazane oil alone, or other dispersion medium may be mixed therewith for controlling the properties such as viscosity and dispersibility of the powder. As such other dispersion medium, there are many suitable materials, such as alcohols including methanol, ethanol, propanol and butanol, ketones including acetone, hydrocarbons including hexane and benzene, and liquid paraffin.

When a suitable fluidity is not obtained in either dispersion medium, the fluidity of the dispersion medium may be controlled by adding a dispersing agent such as oleic acid and/or a thickener such as polyvinyl alcohol, polyvinyl butyral, methyl cellulose, carboxymethyl cellulose, ethyl cellulose, paraffin wax or phenol resin.

The concentration of the slurry of the metal or ceramic powder is preferably higher in the range capable of securing the fluidity necessary for casting, and a suitable concentration 45 to 85 vol. %. When the concentration is less than 45 vol. %, densification in the sintering process is difficult. While, when the concentration is beyond 85 vol. %, to obtain the fluidity necessary for casting is difficult, even though various devices are conducted such as in the particle size distribution of the powder and in the blending of a dispersing agent. A suitable fluidity of the slurry is in the viscosity range of 50 to 10^4 poise.

In the case of removing the dispersion medium by evaporation or thermal decomposition, the mold used is a porous mold. The porous mold must have a strength resistant to the pressure at the time of casting the slurry and gas permeability to permeate the gas produced during heating to remove the dispersion medium to the outside. Suitable materials for the mold include gypsum, the ceramic powder blended with an organic binder, porous sintered ceramics of alumina and the like, porous sintered metals of

stainless steel and the like, and foamed organic materials such as foamed polystyrene and foamed polyurethane. Examples of the ceramic powder include a ceramic powder such as silica sand, alumina or the same ceramic powder as employed for the slurry, and examples of the organic binder include ethyl silicate hydrolyzate, polyvinyl alcohol, polyvinyl butyral, methyl cellulose, carboxymethyl cellulose, ethyl cellulose, paraffin wax, phenol resin and epoxy resin.

An example of the porous mold for the method of the invention is shown in Figure 3. This mold is a split mold, and it can be used repeatedly. On the other hand, a mold for a conventional mold having the same cavity is shown in Figure 4. A cooling pipe 1 is provided on the inside of the conventional mold, and the mold is composed of a material having a high heat conductivity such as aluminum for efficient cooling. Therefore, the conventional mold is necessarily composed of an expensive material and has a complex structure. Another example of the porous mold for the method of the invention belonging to shell mold is shown in Figure 5. This mold is produced by making the pattern of wax, resin such as urea resin, having the shape corresponding to the cavity of the mold, coating the surface of the pattern with a mixture of a ceramic powder and an organic binder in a prescribed thickness, and removing the pattern by steam treatment, thermal decomposition, washing with water or the like. The shell mold is a throwaway type, and has an advantage to meet a complex shaped molding. The organic binder of the shell mold may be a thermally decomposable material. In this case, the shell mold containing the slurry is heated to remove the organic binder together with the dispersion medium in the slurry by thermal decomposition. As a result, the strength of the shell mold decreased, and the following demolding process is facilitated or omitted by self collapse. Suitable organic binders for that purpose include polyvinyl alcohol, polyvinyl butyral, methyl cellulose, carboxymethyl cellulose and ethyl cellulose. A suitable temperature for the thermal decomposition of the binder is 400 to 1200 °C.

In the case of curing the dispersion medium by heating, the mold may be porous or not porous. The mold must have a strength resistant to the pressure at the time of casting the slurry, but since the slurry casting pressure is low, i.e. less than 10 kg/cm^2 , preferably 1 to 5 kg/cm^2 , various materials are applicable. Suitable molds include the aforementioned porous molds and nonporous molds made of metal, rubber or the like. Examples of the metal material are aluminum and stainless steel, and examples of the rubber material are urethane rubber and silicone rubber. In the case of nonporous mold, venting holes may be provided for removing the gas in the mold.

The metal or ceramic powder is kneaded with the dispersion medium, and the slurry is cast into the mold.

In the case of removing the dispersion medium by evaporation or thermal decomposition, the porous mold containing the slurry is placed in a heating apparatus, and heat at a temperature necessary for the evaporation or thermal decomposition of the dispersion medium. During heating, the pressure of the heating apparatus may be reduced. When the dispersion medium is thermally decomposed, the heating temperature of about 400 to 600 °C is usually preferred. After the removal of the dispersion medium, the forming strength of the molded body can be increased by the optional calcination up to about 1,000 to 1,300 °C. Subsequently, the heat-treated body is taken out from the heating apparatus, and demolded to obtain the molded body. A flow diagram illustrating the method of the invention is shown in Figure 1. In the case of a throwaway type shell mold, the following process may be employed. That is, in the thermal decomposition process, the organic binder of the shell mold is thermally decomposed together with the dispersion medium of the slurry to reduce the strength of the shell mold or to be collapsed by itself. Then, the molded body is obtained through demolding, and sintered to form a dense sintered body.

In the case of curing the dispersion medium by heating, the mold containing the slurry of which the dispersion medium contains a silazane oil is placed in a curing oven, and heated at a temperature of 100 to 200 °C to cure the slurry. After the curing, the mold is removed to obtain a molded body. When the molded body is sintered, it is first heated at 400 to 600 °C in a dewaxing oven to decompose thermally the dispersion medium. During heating, the silazane oil is decomposed to produce silicon nitride, silicon carbide or metal silicon. When the atmospheric gas contains oxygen gas or water, silica remains, while, in the nitrogen gas atmosphere, metal silicon may be converted to silicon nitride. In the case of H_2SiCl_2 derived silazane oil, silicon nitride remains, and in the case of (CH_3) $SiHCl_2$ derived silazane oil, both of silicon nitride and silicon carbide can be produced. The molded body is sintered in a sintering furnace to form a dense sintered body. The thermal decomposition and the sintering may be conducted continuously in the same furnace. The sintered body is characterized by containing silicon nitride or silicon carbide derived from the silazane oil. A flow diagram illustrating the method of the invention is shown in Figure 2. As shown in Figure 2, demolding may be conducted after the thermal decomposition.

In the case of removing the dispersion medium by evaporation or thermal decomposition, the formability is imparted to the slurry by removing the dispersion medium through evaporation or thermal

decomposition, instead of utilizing the coagulation of the dispersion medium employed in the conventional method. Though this method requires a longer time compared with the conventional method, since the phase change usually accompanying volume change does not occur in the dispersion medium, the strain and deformation rarely occur in the molded body. As a result, the sintered body obtained has a highly dimentional accuracy. In the conventional method, trial and error experimants are necessary for determining suitable casting conditions, whereas, in the method of the invention the above trial and error expriments are not necessary.

While, in the case of curing the dispersion medium by heating, the silazane oil is cured by condensation polymerization due to heating at 100 to 200 °C, and it is converted from liquid to solid. For example, H_2SiCl_2 derived silazane oil is in a liquid state at ordinary temperature, and is cured by heating at 100 °C for 12 hours, at 130 °C for 5 hours. When the temperature is beyond 150 °C, a slight loss in weight occurs. When the temperature is beyond 200 °C, the loss in weight is appreciably great. In general, in the case of less than 100 °C, the curing time is too long, and in the case of higher than 200 °C, exhaust of the generated gas is necessary. The dispersion medium is cured by curing the silazane oil to impart the formability to the slurry, and the molded body is obtained. As mentioned previously, when not less than 30 wt. % of silazane oil is blended, the molded body has a strength capable of keeping the form after demolding. In this method, since volume change occurs little through the curing of silazane oil, the strain and deformation rarely occur in the molded body. As a result, the sintered body obtained has a highly dimentional accuracy.

EXAMPLES

Example 1

A silicon nitride bolt was prepared. A raw powder composed of 92.0 parts by weight of Si_3N_4 having a mean particle size of 0.75 μm and 6.0 parts by weight of Y_2O_3 having a mean particle size of 0.5 μm and 2.0 parts by weight of Al_2O_3 having a mean particle size of 1.20 μm as sintering aids was mixed with 27.6 parts by weight of liquid paraffin and 3.0 parts by weight of oleic acid, and kneaded for 24 hours. The obtained slurry was defoamed by exposing it to vacuum. A shell mold having a cavity corresponding to the bolt shown in Figure 6 and Figure 7 was formed by using a mixture of 100 parts by weight of the above silicon nitride and 5 parts by weight of polyvinyl butyral as a binder. The above slurry was cast into the shell mold at 22 °C at a casting pressure of 3 kg/cm^2. The casting pressure was temporarily decreased at the start of casting. After the casting pressure was recovered up to 3 kg/cm^2, the mold containing the slurry was immediately detached. The mold was placed in a dewaxing furnace, and the temperature was elevated to 500 °C at an elevating speed of 3 °C/hr with passing nitrogen gas. When the temperature reached 500 °C, the temperature was kept for 2 hours. Then, the mold was naturally cooled. The mold was very fragile, and it was easily removed to obtain a sound molded body. The molded body was buried in a packing powder composed of 50 wt. % of Si_3N_4 and 50 wt. % of SiO_2, and placed in a sintering furnace. The temperature was elevated to 1200 °C in vacuo, and kept for 30 minutes. Subsequently, the temperature was further elevated to 1800 °C, while nitrogen gas was passed at 9.5 kg/cm^2, and kept for 2 hours. The molded body was cooled to 1000 °C, while the gas pressure was kept at 9.5 kg/cm^2. Then, the pressure was returned to atmospheric pressure, and the molded body was naturally cooled.

Thus, a sintered body having a theoretical density ratio of 98.1 % was obtained. Each contraction ratio at the part A, the part B, the part C and the part D of the bolt-shaped sintered body was measured, and the results are shown in Table 1. The dispersion of the contraction ratios was only 0.2 %.

Table 1

Part	Mold Size (mm)	Sintered Body of Example 1		Sintered Body of Comparative Example 1	
		Size (mm)	Contraction Ratio (%)	Size (mm)	Contraction Ratio (%)
A	31.0	25.4	18.1	25.3	18.4
B	12.2	10.0	18.0	9.9	18.9
C	73.2	60.0	18.0	59.3	19.0
D	16.5	13.5	18.2	13.4	18.8
Max-Min	-	-	0.2		0.6

Comparative Example 1

A comparative silicon nitride bolt was prepared by using a bolt mold having the same shape and size as employed in Example 1. 100 parts by weight of the same raw powder as Example 1 was mixed with 27.6 parts by weight of paraffin having a melting point of 42 °C and 3.0 parts by weight of oleic acid, and kneaded at 90 °C for 24 hours. The obtained slurry was deformed by exposing it to vacuum. The slurry was cast at 90 °C at a casting pressure of 3 kg/cm^2 into a mold cooled by passing a coolding water at 10 °C. After the casting pressure was recovered up to 3 kg/cm^2, the state was kept for 5 minutes for completing the freezing of the slurry, and then, the molded body was demolded. Subsequently, the molded body was placed in the extracting apparatus, and extraction was carried out by passing supercritical carbon dioxide at 200 kg/cm^2 at 60 °C for 4 hours. Thus, a mixture of paraffin and oleic acid corresponding to 62 wt. % of the dispersion medium in the slurry was extracted. Subsequently, the molded body was placed in a pressure dewaxing furnace, and the temperature was elevated at an elevating speed of 100 °C/hr under nitrogen gas atmosphere by passing it at a pressure of 6 kg/cm^2. When the temperature reached 500 °C, the temperature was kept for 1 hour. Then, the mold containing the extracted body was naturally cooled, and the pressure was returned to atmospheric pressure. Thus, the dispersion medium was completely removed. The molded body was sintered under the same conditions as Example 1, and a sintered body having a theoretical density ratio of 98.4 % was obtained. Each contraction ratio of the sintered body was measured, and the results are also shown in Table 1. The dispersion of the contraction ratios was 0.6 %, and it was inferior to those of Example 1.

Example 2

A silicon nitride bolt was prepared. A raw powder composed of 92.0 parts by weight of Si_3N_4 having a mean particle size of 0.75 μm and 6.0 parts by weight of Y_2O_3 having a mean particle size of 0.5 μm and 2.0 parts by weight of Al_2O_3 having a mean particle size of 1.20 μm as sintering aids was mixed with 19.3 parts by weight of liquid paraffin, 3.0 parts by weight of oleic acid and 10.3 parts by weight of H_2SiCl_2 derived silazane oil, and kneaded for 24 hours. The obtained slurry was deforamed by exposing it to vacuum. A shell mold having a cavity corresponding to the bolt shown in Figure 6 and Figure 7 was formed by using a mixture of 100 parts by weight of Al_2O_3 powder having a mean particle size of 1.20 μm and 5 parts by weight of polyvinyl butyral as a binder. The above slurry was cast into the shell mold at 22 °C at a casting pressure of 3 kg/cm^2. The casting pressure was temporarily decreased at the start of casting. After the casting pressure was recovered up to 3 kg/cm^2, the mold containing the slurry was immediately detached. The mold was placed in a curing oven, and heated at 150 °C for 10 hours under nitrogen gas atmosphere, and then, naturally cooled. The mold was destroyed to obtain a sound molded body. The molded body was placed in a dewaxing furnace, and the temperature was elevated at an elevating speed of 3 °C/hr with passing nitrogen gas. When the temperature reached 500 °C, the temperature was kept for 2

hours. Then, the molded body was naturally cooled. The dewaxed molded body was sintered similar to Example 1.

Thus, a sintered body having a theoretical density ratio of 98.6 % was obtained. Each contraction ratio at the part A, the part B, the part C and the part D of the bolt-shaped sintered body was measured, and the rasults are compared with Comparative Example 1 in Table 2. The dispersion of the contraction ratios was only 0.2 %

Table 2

Part	Mold Size (mm)	Sintered Body of Example 1		Sintered Body of Comparative Example 1	
		Size (mm)	Contraction Ratio (%)	Size (mm)	Contraction Ratio (%)
A	31.0	26.0	16.1	25.3	18.4
B	12.2	10.2	16.0	9.9	18.9
C	73.2	61.5	16.0	59.3	19.0
D	16.5	13.8	16.2	13.4	18.8
Max-Min	-	-	0.2		0.6

Claims

1. A method of casting a metal or ceramic powder which comprises casting a slurry of the metal or ceramic powder suspended in a dispersion medium into a porous mold and heating the slurry placed in the porous mold to remove the dispersion medium through the evaporation or the decomposition of the medium.

2. The method of claim 1 wherein said dispersion medium is liquid paraffin.

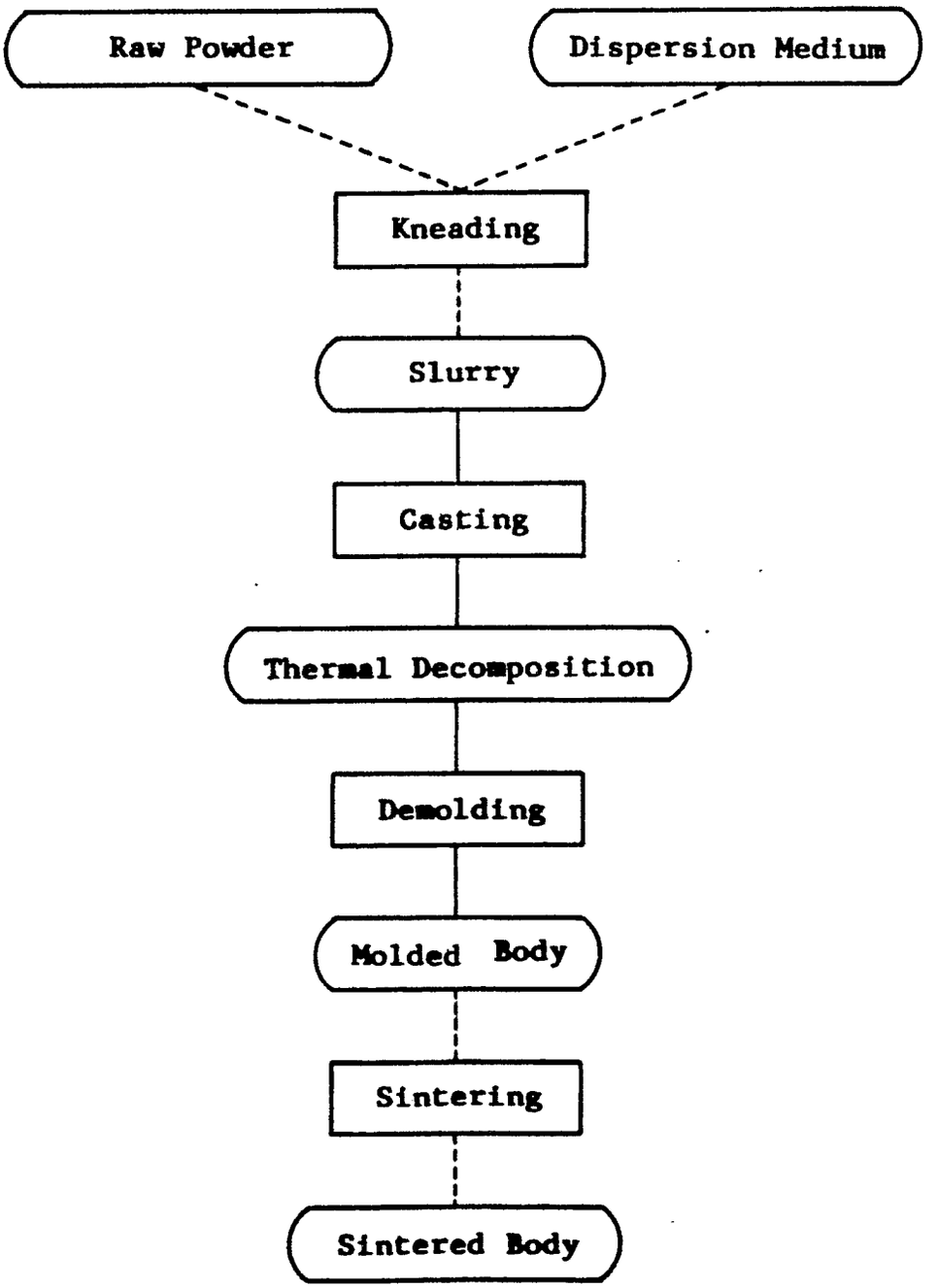
3. A method of casting a metal or ceramic powder suspended in a dispersion medium containing at least 30 wt. of a silazane oil into a mold, curing the dispersion medium by heating at a temperature of 100 to 200 ° C, and then demolding.

4. The method of claim 1,2 or 3 wherein said dispersion medium contains a dispersing agent and/or a thickener.

5. The method of claim 1 or 3 wherein said mold is a shell mold containing an organic binder.

6. The method of claim 5 wherein said organic binder is a member selected from polyvinyl alcohol, polyvinyl butyral, methyl cellulose, carboxymethyl cellulose and ethyl cellulose.

FIG. 1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Dispersion Medium
Kneading
Slurry
Casting
Thermal Decomposition
Demolding
Molded Body
Sintering
Sintered Body

FIG. 2

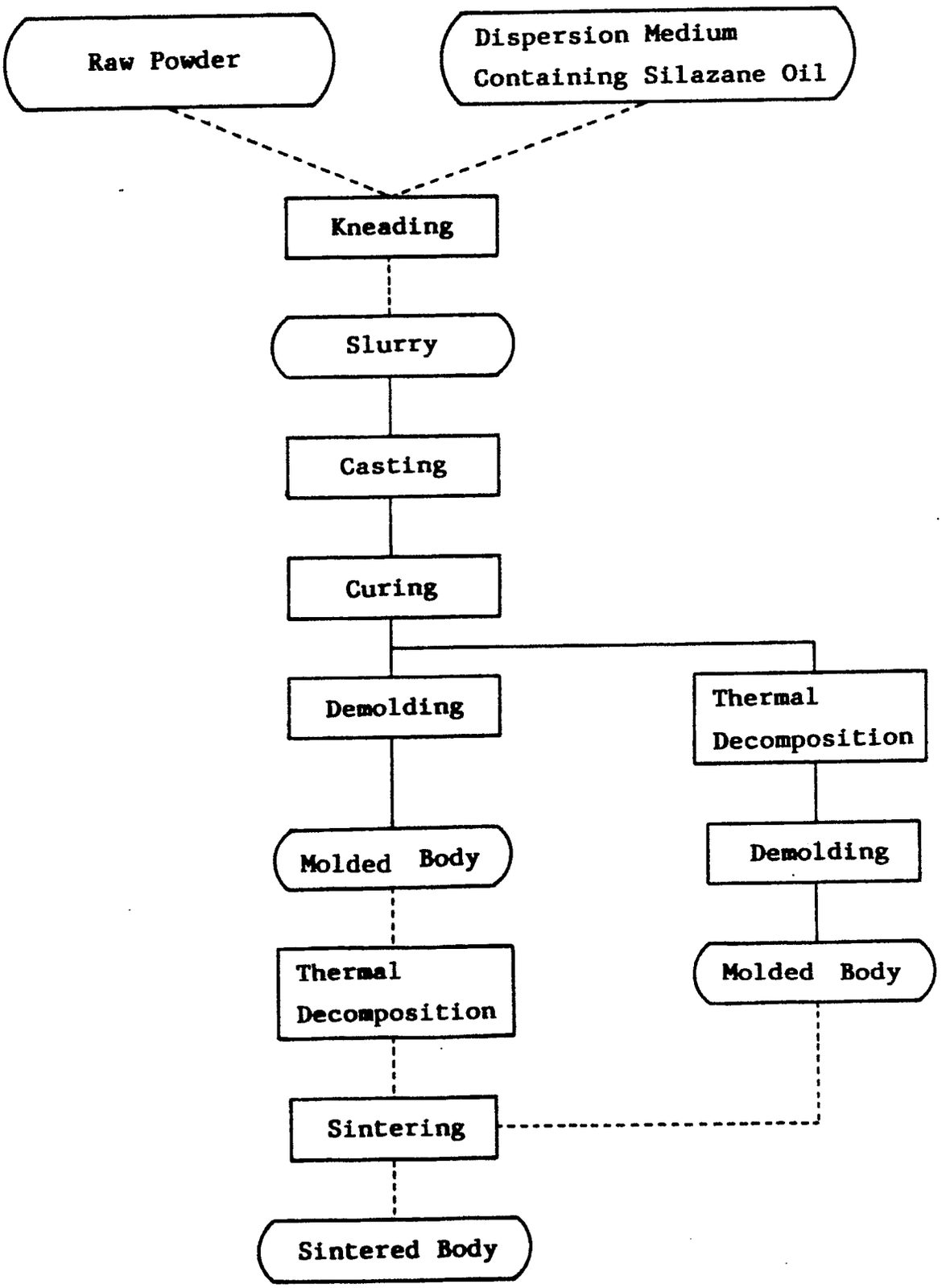

Raw Powder
Dispersion Medium Containing Silazane Oil
Kneading
Slurry
Casting
Curing
Demolding
Thermal Decomposition
Molded Body
Demolding
Thermal Decomposition
Molded Body
Sintering
Sintered Body

FIG. 3

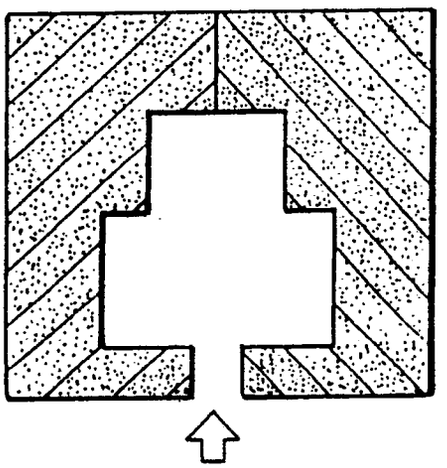


FIG. 4

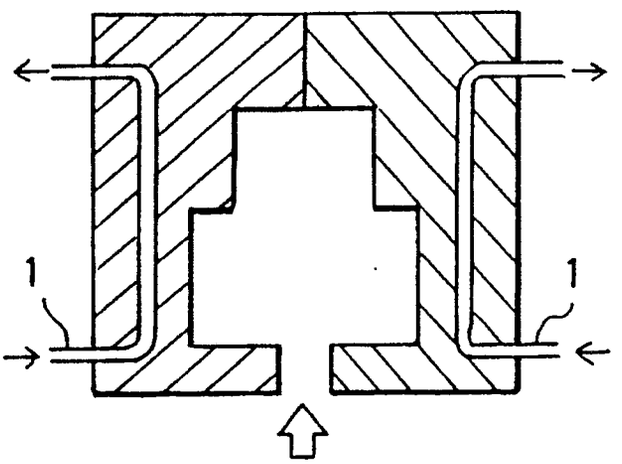


FIG. 5

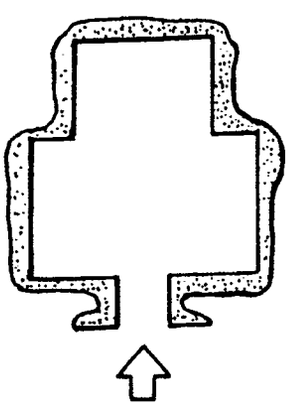


FIG. 6

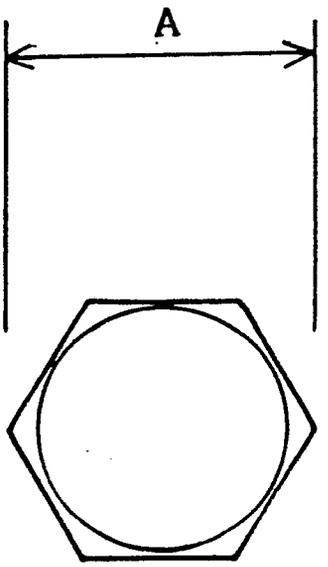


FIG. 7

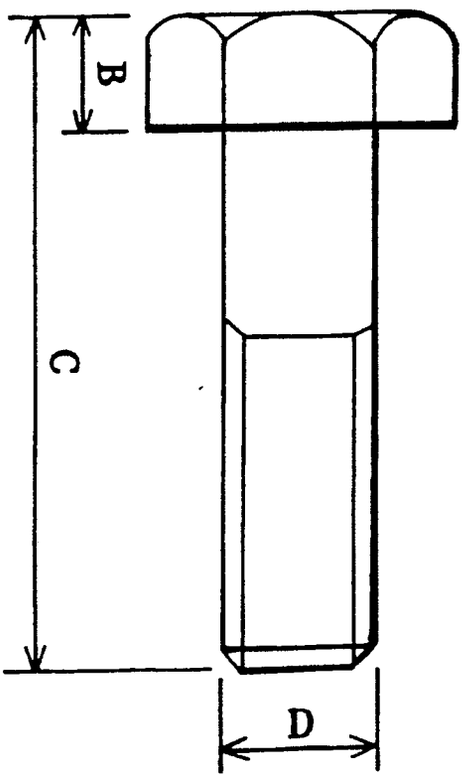
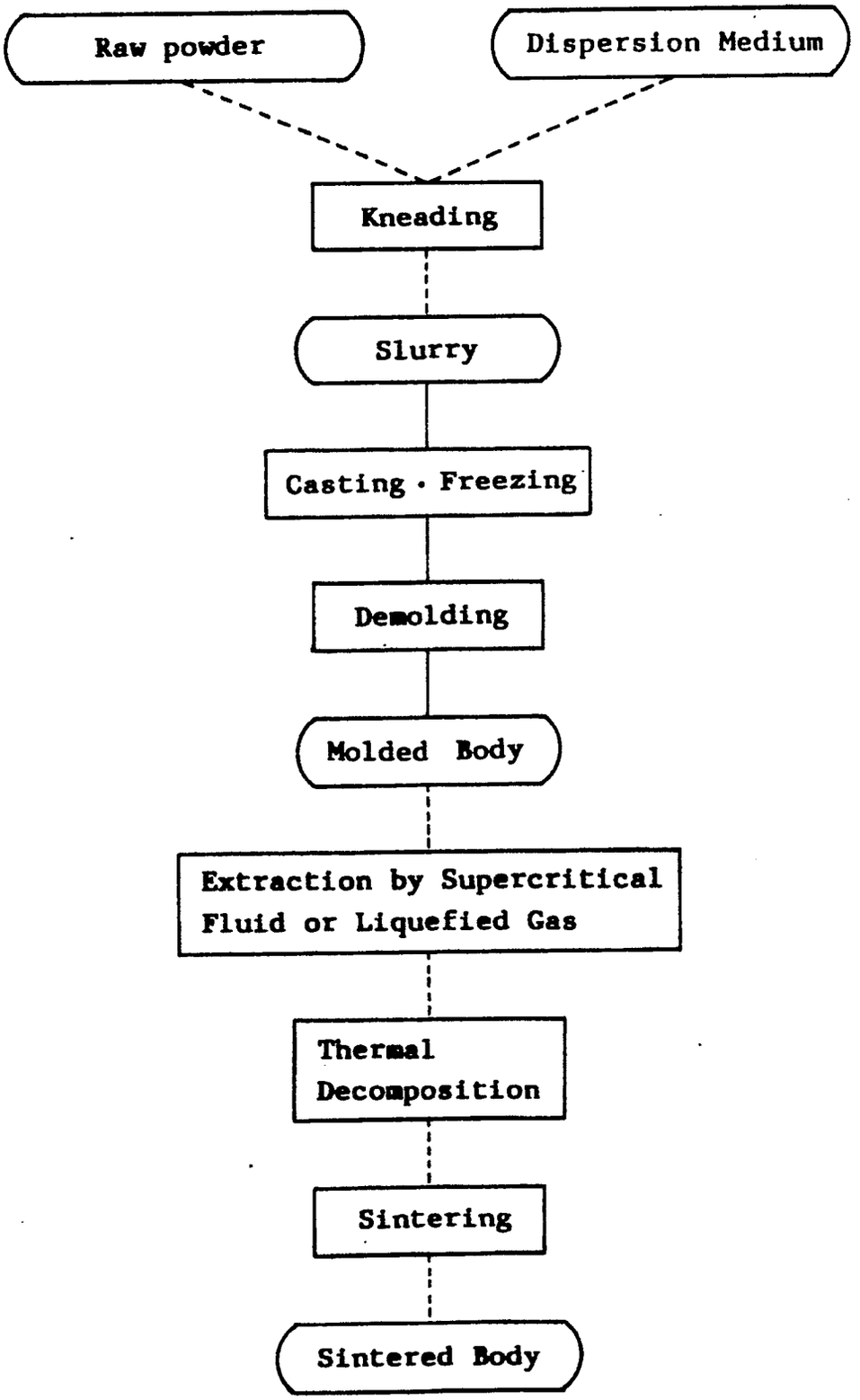


FIG. 8


Raw powder
Dispersion Medium
Kneading
Slurry
Casting · Freezing
Demolding
Molded Body
Extraction by Supercritical Fluid or Liquefied Gas
Thermal Decomposition
Sintering
Sintered Body

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 90 11 1776

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	US-A-2 894 837 (E.I. ONSTOTT et al.) * Claim 1; column 3, line 52 - column 4, line 20 *	1-2,4	B 22 F 3/22 C 04 B 35/00 B 28 B 1/26
Y		5-6	
X	FR-A-2 504 425 (ASULAB) * Claims 1,2,6,18 *	1-2	
Y	FR-A-2 504 424	5-6	
X	PATENT ABSTRACTS OF JAPAN, vol. 7, no. 254 (M-255), 11th november 1983; & JP-A-58 136 702 (ISHIKAWAJIMA HARIMA JUKOGYO) 13-08-1983	1-2	
X	EP-A-0 305 759 (GTE) * Claims 1,4; page 3, examples 3,4 *	3	
Y		5-6	
Y	EP-A-0 191 409 (HITACHI) * Claims 1-3 *	5-6	
A	DE-B-1 533 035 (TAVKÖZLESI KUTATO INTEZET) * Claim 1 *	1	TECHNICAL FIELDS SEARCHED (Int. Cl.5) B 22 F C 04 B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	30-08-1990	SCHRUERS H.J.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
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T : theory or principle underlying the invention
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